Study of peculiarities of hydrochemical mode of surface waters in conjunction with ground waters at a time and in boundary conditions of physical model of infiltration basin (on the example of Karatal area of experimental researches of artificial waterspreading in South East Kazakhstan)

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Abstract

Surface waters in conjunction with ground waters at a time and in boundary conditions of physical model of infiltration basin as a part of system of their artificial waterspreading (hereinafter AW) in the experimental area in the middle reach of Karatal in south-east Almaty region are the **object of research**.

The objective of research: carrying out scientific and laboratory innovative researches as a part of:

- studying of the hydrochemical and sanitary-bacteriological mode of river run-off of Karatal as AW source seasonably and in long-term view;
- studying of the river pollution level and changes of ground waters quality when their artificial waterspreading considering the processes of mixture and self-purification during infiltration in boundary conditions of the created physical model of mini-basin;
- studying of clogging process and silting-up of infiltration constructions in the experimental area of AW including determination of turbidity of a surface waters in the field environment with the use of innovative technologies.

Methodology consists in scientific innovative instrumental, system and analytical methods of alternative statistics during studding of hydrochemical and sanitary-bacteriological mode of surface and ground waters at a time on physical model of basin in simulated environment of its infiltration recharge with the use of distant-action instruments and the equipment for monitoring and diagnostics.

Studying of these processes was based on the modern technological approaches exiting in the world practice to this problem and was carried out in purposely arranged unique experimental area of AW system relating to certain environmental conditions.

Originality/value. In the article, we can find actual results of field and laboratory studies of ecological monitoring and hydrochemical and sanitary-bacteriological mode of river run-off in conjunction with ground waters in actual practice of artificial additional ground waters recharge for domestic water supply of rural community.

The distinctive features, which are of value of scientific work, are the following: the suggested applied recommendations on the use of surface waters of river run-off as only potential source of waterspreading seasonably and in long-term view considering the pollution level of the river and infiltration basins, and the forecast of quality changes of ground waters when artificial waterspreading considering the processes of mixture and self-purification during infiltration.

Results. The definite characteristics of hydrochemical and sanitary-bacteriological mode of waterspreading source, the river pollution level and infiltration basins were obtained.

On the basis of the obtained results, the practical recommendations on the use of river run-off as source for AW installation throughout the year (except for the high-water period and the subsequent stabilization of river run-off) without preliminary mechanical purification and sanitary-epidemiological treatment were developed.

The long-term forecast of ecological indicators of ground waters when artificial waterspreading considering the processes of mixture and self-purification during infiltration was made.

Regularities of influence of clogging process on the silting-up level of infiltration constructions in the case of AW area were revealed, and the long-term forecast of the infiltration basins operational mode was made.

Key words: ARTIFICIAL WATERSPREADING, ECOLOGICAL MONITORING, SURFACE WATERS, HYDROCHEMICAL MODE, GROUNDWATER RESERVOIR, INFILTRATION BASIN, INFILTRATION, PHYSICAL MODEL, CLOGGING, POLLUTION LEVEL, MECHANICAL PURIFICATION, SANITARY-EPIDEMIOLOGICAL TREATMENT

Introduction

The current state and relevance of conducted scientific researches of the hydrochemical and sanitary-bacteriological mode of river run-off in conjunction with ground waters and analysis of ecological monitoring in actual practice of artificial additional ground waters recharge for domestic water supply of rural community are caused by lack of water sources in the territory of South East Kazakhstan because of large distance from the consumer or nonconformity of quality to the modern requirements applicable to domestic waters. In this regard, providing the population with domestic water, including water from underground layers, in sufficient quantity and normative quality, and also problems of the combined use of surface and ground waters and their artificial recharge become a priority task [5]. At that, the objects accessible for development considering real people need for water, intensification of earlier explored field of ground waters and evaluation of water treatment conditions with application of modern technologies should be emphasized.

The surface water use when artificial waterspreading predetermines the need of the characteristic of the hydrochemical and sanitary-bacteriological mode of waterspreading source seasonably and in long-term view, the level of river pollution and infiltration basins considering geologic-lithological features of constructions on the AW systems [1].

Thus the following criteria are used:

- presence of the potential consumer of accumulated waters in the AW areas. The rural communities with inhabitants quantity from 500 to 2000 considering growth prospect. These communities include the ones, which did not enter the list of objects of domestic water supply of the "Ak-Bulak" program. They are those where either residents use imported water as domestic one, or the available surface water sources do not meet the sanitary-epidemiological requirements;
- existence of the water-bearing layers possessing sufficient potential for acceptance of the corresponding volume of the accumulated ground waters reserves of required quality and quantity. We take into account the thickness and lithological composition of the potential water-bearing layer; existence of the natural borders in plan and in section allowing us to create the closed circuit (the underground reservoir for water with its subsequent use); depth of the potential water-bearing layer;
- existence of a potential water source for AW possessing necessary amount of water of required quality. Considerable importance is attached to the distance from a water source to AW area;
- possibility of protection of the accumulated ground waters reserves from pollution by external sources, and also environmental protection in AW areas. Such potential sources of pollution can be the following: underground inflow of poor quality waters from the area external borders, and also an overflow from adjacent water-bearing layers; an infiltration from off-spec waters surface (irrigation, run-off); dissolution of water-soluble salts and the polluting components at rise in levels of underground waters in the water-bearing layer; dissolution of water-soluble salts and the polluting agents when rising of ground waters level in the water-bearing layer;
- possibility of use of the selected AW area as standard one for distribution of the obtained data in similar areas for further introduction and use of researches results;
- possibility of experimental works organization in the area;
- cost and other technical and economic features.

As a result, the site located in the territory adjacent to the village Kishi-tobe, being the potential consumer of water by means of ground waters when artificial waterspreading of their reserves, is selected as the most acceptable and alternative object of scientific researches according to the article subject.

The location of researches area in the territory of the Republic of Kazakhstan in Almaty region is shown in Fig. 1.

1. The organization of ecological monitoring and the hydrochemical mode of surface and ground waters in the researches area

The researches were conducted in the region defined as the most perspective for a solution of the problem of domestic water supply of rural communities in a river basin Karatal.

The river Karatal feeds ground waters almost throughout the entire territory, and the insignificant outcrop of ground waters into the bed is observed only on exit of Taldy-Kurgan Depression [20].

The water-bearing layer ungraded modern and modern upper quarternary alluvial deposits (alQ_{IV}–$alQ_{III}-_{IV}$) gained widespread in the calculated area of the experimental researches field.

The area under investigation is coincided with floodplain and terrace above the floodplain. The water-bearing materials are presented by the interlaid loamy light sand and fine-grained sand, frequently by micaceous and partially by clay ones with lenses of gray-cinnamon weakly heavy clay.

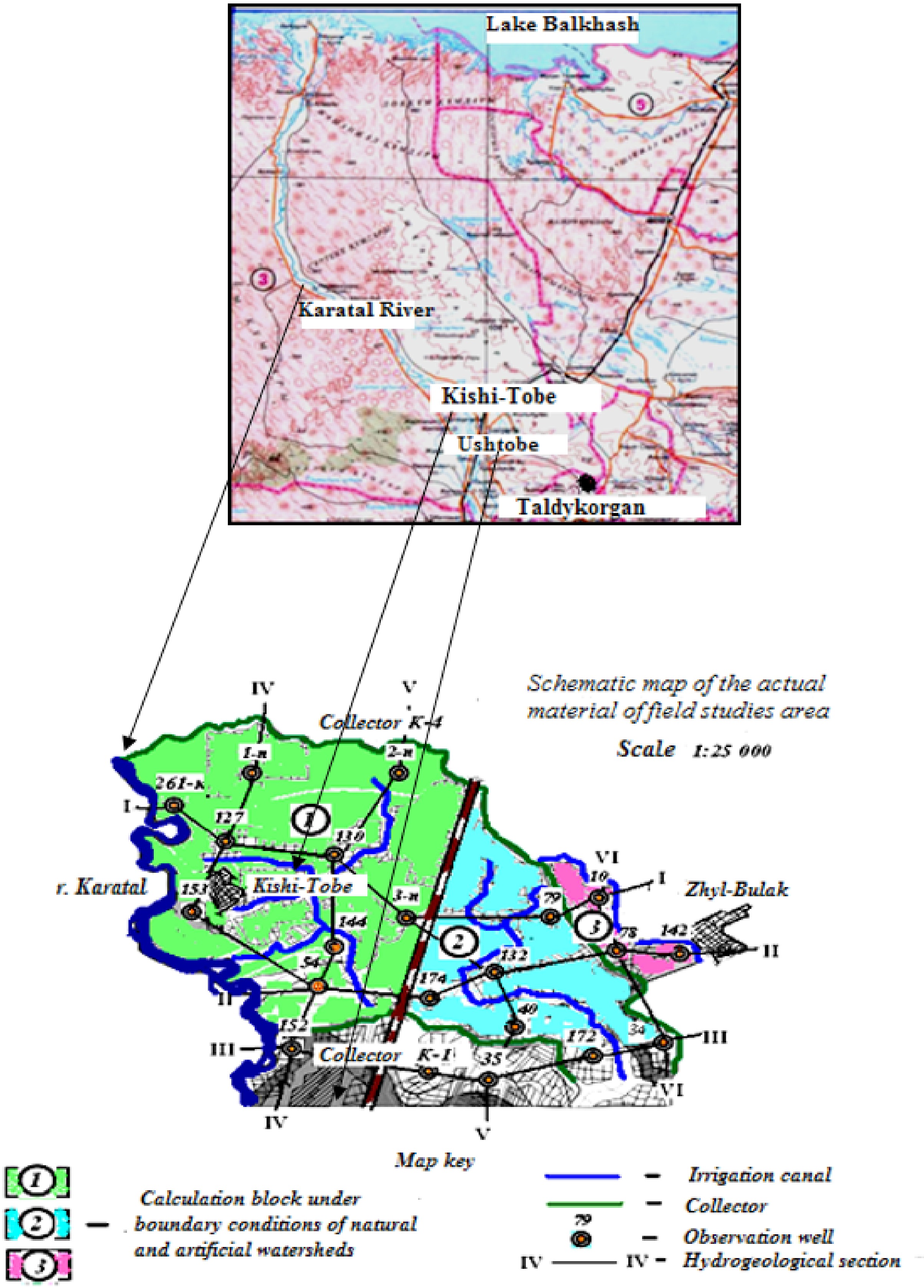


Figure 1. Location diagram and map of the actual material of researches field

The average thickness of water-bearing layer is from 5-7 to 10-12 meters. The coefficient of conductivity varies from 1 to 3- 4 m/day. The ground water depth level reflects the land forms almost in inversed manner and is changed during ground waters north-westward transit and eastward with distance from the floodplain of river Karatal from 4-5 and more meters to 2-3 m.

When selecting of the infiltration basin location, its minimum and technically possible distance from Kishi-Tobe taking into account its master plan of building-up till 2030 and prospects economic development was considered [5].

The AW installation possible diagram based on results of model calculations is shown in Fig. 2 [13].

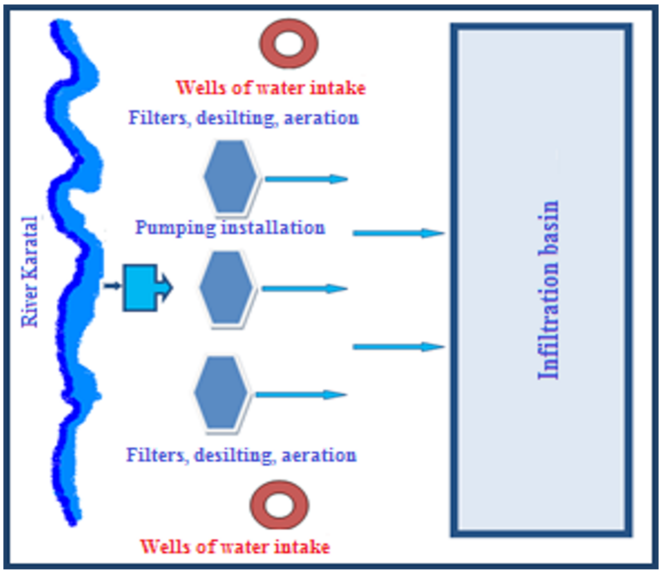


Figure 2. Layout diagram in case of single-row location of capitation and infiltration constructions
1– surface source of r. Karatal; 2. – water intake; 3. – first stage pumping installation; 4. – preliminary preparation constructions; 5. – infiltration basin; 6. - operational wells for domestic water supply of the village Kishi-Tobe

In the center of an experimental field, the surface hole was developed. This hole simulates the future daily run-off infiltration basin on a reduced scale with the following parameters: laying depth – 4.0 m with natural slopes and top dimensions - 2x5 m. Two temporary observation wells-piezometers were drilled to the level of ground waters in order to study the ground waters mode formation directly under the bottom of mini-basin at distance of 1.5 and 3.0 m from east slope of the mini-basin [5].

The mini-basin was filled with the water from river Karatal from measuring container with volume of 4m^3; it is equipped with flowmeter and is constantly filled by means of automatic water carrier with tankage capacity of 8 m^3.

The location of geological openings complex at the experimental field is schematically represented in Fig. 3.

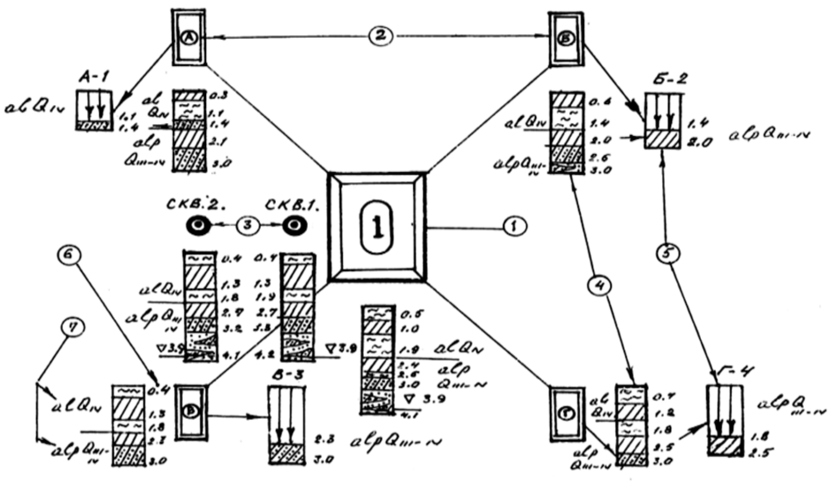
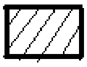
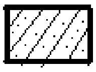


Figure 3. The diagram of location of geological openings complex at the experimental field

Conventional symbols: 1. - The central hole - physical mini-model of the infiltration basin; 2. - the holes located across the designed infiltration basin; 3. - observation wells-piezometers; 4. – geologic-lithological section, at the left (7) - geological index, at the right (6) - a depth of massive material bottom layer of section, m; 5. – the diagram-section of the uncover massive material

 - loam  - sandy loam  - fine-grained sand with lenses of sandy loams  - clay

Sampling was carried out in order to study the surface and ground water quality at the experimental field. Thus, sampling points were attached to cross sections, where the instrumental water control was carried out. Micro-components, pesticide chemicals and oil products samples for shortened chemical analysis were taken twice a year (June and August).

The mode of ground waters in the area was studied on 2 monitoring wells surrounded by polyvinylchloride and three-observation metal pipes via measurement of ground waters depth in winter once a month, and each ten days during irrigation period (from May to September) [20]. The ground waters level in wells was measured by the water-level meter with an accuracy of measurements to 1-2 cm.

The water intake from monitoring and observation wells is carried out two times (in June and August) in order to study the chemical composition and measure the pollution by organochlorine pesticides, oil products and heavy metals. Previously, 1-2 days before sampling, the water was pumped out from wells by means of handle sampling spoon in an amount of two thirds of volume of water head.

Besides that, layer-by-layer surface water sampling from the river Karatal was carried out from the mini-basin in the simulated AW system; the samples were used as AW sources during experimental researches while the basin filling by these waters, and also their observation piezometers and wells at the subsequent processes of infiltration in the modelled water-bearing layer.

The complete complex of laboratory researches of chemical composition of heavy metals salts, contents of oil products and other polluting ingredients was carried out in the accredited laboratory using the taken samples.

In Fig. 4, location and name of sampling points of water are marked on the schematic map of the actual material of experimental researches area.

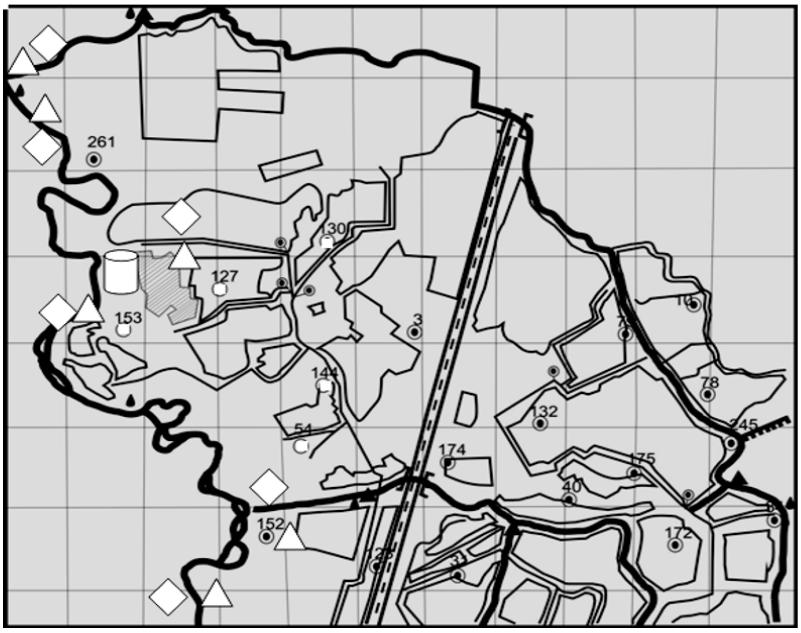


Figure 4. Schematic map of the actual material of experimental researches area of ecological monitoring and hydrochemical mode of surface and ground waters

△ - sampling point of surface river and collector and drainage waters for the complete chemical analysis;

◇ - sampling point of surface river and collector and drainage waters for polluting ingredients

 - sampling point of soils for standard reference material (SRM) across the physical minimodel of the infiltration basin at an experimental field;

□ - sampling point of ground waters for complete chemical analysis and polluting ingredients.

2. Results of ecological monitoring and researches of the hydrochemical mode of surface and ground waters.

When artificial waterspreading of ground waters reserves, the qualitative composition of water incoming to recharge is of great importance. It determines substantially an operating mode of infiltration constructions and quality of water obtained on a water intake of ground waters [7].

Results of laboratory analyses of the surface water samples, which were taken in the river Karatal in the cross section of area of the recommended water intake from the river for AW, showed that during field researches and experiment, water salt content was changed slightly from 450 mg/dm^3 (2010-2011) to 250 mg/dm^3 (2013-2014), and the chemical composition was changed from hydrocarbonate-sulfate calcium-magnesium to hydrocarbonate- chloride calcium-sodium.

The value of hydrogen index varied from 7.5 to 8.0. The sodium adsorption ratio (SAR) was not higher than 2.5.

The dynamics parameters (Fig. 5) of the total salt content and chemical composition of surface waters of river Karatal show that from 2010 to 2014 insignificant fluctuations and decrease in the total salt content mine are observed; they are caused by various river flows on an annual basis of the given period. For example, 75% probability was illustrative in 2010-2011 dry years, and according to the established cyclicity, 50% probability was illustrative of 2014 according to dryness of the year. Therefore, surface water of river Karatal conforms to all the requirements “Drinking water” according to its chemical composition and salt content and can be used as the suggested source of AW for water supply of Kishi-Tobe regardless of dryness of the year.

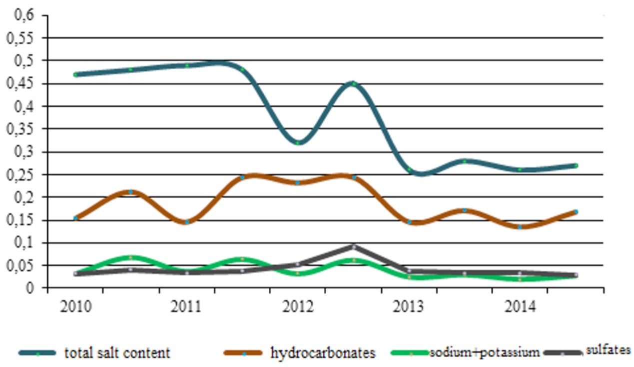


Figure 5. Change of the total salt content and chemical composition of surface water of river Karatal, mg/dm^3

Layer-by-layer surface water sampling from the river Karatal was carried out from the mini-basin in the simulated AW system; the samples were used as AW sources during experimental researches while the basin filling by these waters, and also their observation piezometers and wells at the subsequent processes of infiltration in the modelled water-bearing layer. The researches were conducted at five-fold replication of the mini-basin filling before complete saturation of the deposits occurring in overlying of the water-bearing layer and stabilization period of ground waters infiltration recharge in the area of simulated system of AW. The cameral treatment results of the complete chemical analyses of ionic composition dynamics of surface waters in time and intervals of their testing during the filling and emptying of the mini-basin are shown in the spider diagram in Fig. 6. Thus, the stable ratio of anions and cations in chemical composition of the river water used for filling of the mini-basin to the third cycle of process replication from complete saturation of deposits in the construction base to the established water infiltration in the water-bearing layer is the characteristic feature. Henceforth, when preserving of total salt content level, the hydrocarbonates are reduced considerably while chlorine and sodium content is increased with dependent increase in other ions. It is evidently caused by infiltration rate reduction due to gradual clogging of sandy fractions of covering deposits and clay coating formation in the mini-basin base.

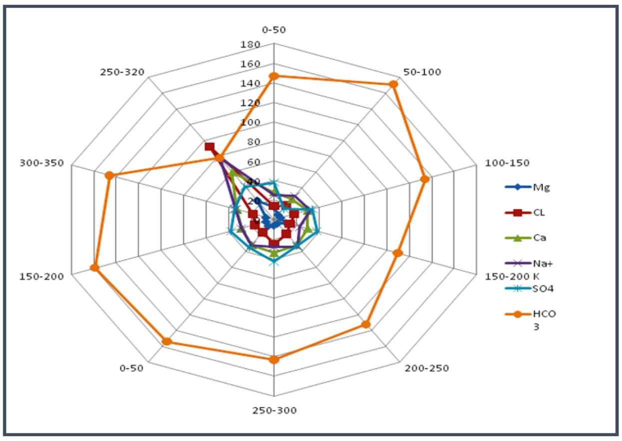


Figure 6. Ionic composition dynamics of surface waters in time and intervals of their testing during the filling and emptying of the mini-basin

During the analysis of results, which were developed and shown in Fig. 7, considering change of ionic composition of surface waters in time and intervals of their testing during the filling and emptying of the mini-basin, the clear tendency is observed:

- reduction of ground waters total salt content in the observation piezometers, which are close to mini-basin on the 4-5th cycle of its filling and empting due to close hydraulic connection of ground waters

- and their chemical interaction with infiltration more fresh surface waters, which have flown to the top water-bearing layers. At that, ions of sulfates and chlorine are the most active, and hydrocarbonates indexes are stable;
- insignificant, but positive changes of total salt content as well as ionic composition of ground waters are noted in the observation wells located out of conventional borders of the infiltration basin within the radius of impact of planned water-intake wells. The slightly marked tendency to water samples slight change towards concentration reduction is observed only at the end of the experimental researches period.

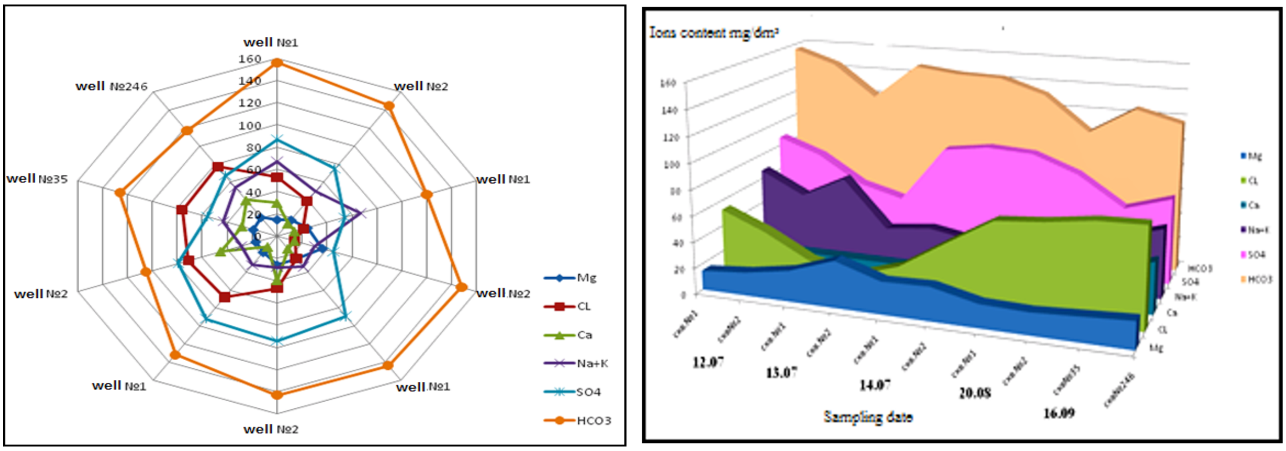


Figure 7. Dynamics of ionic composition of ground waters in observation wells and piezometers in time and intervals of their testing during the filling and emptying of the mini-basin

The data of field and laboratory researches of hydrochemical mode of surface and ground waters were used for the designed geofiltration model validation.

3. Results of ecological monitoring of surface and ground waters.

The field and laboratory researches on study of pollution of river Karatal waters, irrigation and drainage-spill waters were conducted in the area under investigation. Also ground waters samples from observation wells were taken. In the course of investigations, the composition of heavy metals, oil pro-ducts and bacteriological pollution was determined (coli-phage, coli-index, total microbial count).

The incidental and imperceptible increase in content of copper and zinc is noted in the river water. In Fig. 8, it is distinctively seen that concentration of copper in water was 0.002 in June, 2014; this value exceeded the admissible concentration limit for objects of fishery value by factor of 2 (the content of copper exceeded admissible concentration limit by factor of 3.6 in 2010 before vegetation). In comparison with 2013, the content of zinc in irrigation water exceeded norms of admissible concentration limit by factor of 2.6; in September, 2013 this limit was 0.026 mg/dm^3 (in May, 2010 it was 0.0102 mg/dm^3).

In general, results of long-term observations give grounds for drawing of a conclusion that there are practically no salts of heavy metals in river water. The incidental and short-time occurrence of copper and zinc in river water (exceeding admissible concentration limit insignificantly) is due to geological-structural features of formation area of river Karatal run-off and to natural processes of rocks leaching.

The lead content, which was 0.012 mg/l in September, was insignificantly higher than admissible concentration limit in the spill water. The content of other microcomponents was within norm and did not exceed the existing admissible concentration limits in drainage-spill waters during the entire observation period.

The admissible concentration limit was exceeded with copper, zinc and mercury (isolated case) in ground waters of one of observed wells. Excess of these metals is of incidental nature and is obviously related to their high concentration in soils in case of artificial fertilizers overdose.

The oil products concentration is not over the limit in all the samples. Results of the bacteriological analysis of surface and drainage water showed that exceeding of coli-phage, coli-index, total microbial count is not revealed. The water corresponds to GOST “Drinking water”.

Figure 8. The content of zinc and copper in surface, collector and drainage and ground waters in the experimental researches area, g/l

3.1. Technogenic pollution of soils in the experimental researches area.

There is no technogenic pollution onsite. The processes of land degradation are related to their use in agricultural production. Mineral and organic fertilizers, toxic chemicals, household wastes are the main sources of soils pollution during irrigated agriculture. Excessive use of artificial fertilizers leads not only to pollution of the soil, but also to cash crop quality degradation.

The conditions of storage, transportation and technology of application of artificial fertilizers and toxic chemicals are important for prevention of soils pollution. The soils pollution was studied on the base of SRM.

Besides that, the combined sample of topsoils were taken in 8 points according to the existing requirements for the spatial characteristic of possible pollution; these samples were analyzed in central laboratory support "Ekogidroanalitik". The results of these measurements demonstrate that the content of all these ingredients is lower than the admissible concentration limit (ACL). It allows us to draw a conclusion that the soils are not polluted at the present time.

Conclusion

The surface water use when artificial waterspreading predetermines the need of the characteristic of the hydrochemical and sanitary-bacteriological mode of waterspreading source seasonably and in long-term view, the level of river pollution and infiltration basins considering geologic-lithological features of constructions in the AW representative area [1].

During 2010-2014, the samples of river Karatal water, collector and drainage and ground waters, and also samples of soils in the physical mini-model installation area of the infiltration basin in the sample area were taken.

From 2010 to 2014 insignificant fluctuations and decrease in the total salt content mine are observed; they are caused by various river flows on an annual basis of the given period. Thus, surface water of river Karatal meets all the requirements of "Drinking water" according to the chemical composition and salt content in the function of the recommended AW source for water supply of village Kishi-Tobe.

The results of long-term observations give grounds for drawing of a conclusion that there are practically no salts of heavy metals in river water. The incidental and short-time occurrence of copper and zinc in river water (exceeding admissible concentration limit insignificantly) is due to geological-structural features of formation area of river Karatal run-off and to natural processes of rocks leaching.

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The location of researches object on the middle reach of river Karatal predetermines formation of breaking-up products or a so-called solid run-off in water and transit of them by water; thus, smaller material moves in water flow in the form of suspended particulate matters. The water turbidity depends on its volume.

The field studies of clogging processes of the mini-basin were carried out by measurements of contaminant capacity or turbidity of the river water pumped to the infiltration mini-basin. The instrument Mutnomer Turb355T/IR with complete package, and also a photometric method of comparison of water samples under investigation with standard suspended matters were used.

These researches allowed us to draw the following conclusions on water turbidity in the river Karatal:

- surface waters of river Karatal are characterized by the low content of the suspended mechanical particles – from 3.5-4.0 mg/l to 12.0 – 15.0 mg/l during the middle-summer and autumn-winter periods, except for the periods of flood run-off when their turbidity reaches to 120-150 mg/l;
- the water was naturally cleared and its turbidity was reduced to the minimum values of 2.5-2.7 mg/l during the experiments in the infiltration mini-basin while decreasing in its water level;
- the waters of river Karatal are recommended to use as a source for the AW installations intended for domestic water supply of the village Kishi-Tobe throughout the year (except for the high-water period and the subsequent stabilization of river run-off) without preliminary mechanical purification and sanitary-epidemiological treatment;
- the thickness of clay coating at the dock apron was only 0.09 mm while the volume of the filtered water was 7.284 m^3; this thickness is so small that gives the basis to draw a conclusion that there is no danger for pores cogging of the water-bearing materials of the layer presented by fine-grained sand.

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